

Nuclear Structure and Reactions

I.-Yang Lee

The nuclear structure and reactions program focuses on the study of the static and dynamic properties of nuclei at conditions of extreme angular momentum, temperature, proton number, and neutron number, as well as using nuclei as a quantum system to test fundamental symmetries and understand the weak interaction. Most of the studies use beams provided by the 88-Inch Cyclotron and state of the art instrumentation developed at LBNL. Three new instruments became operational this year; the 8-pi gamma-ray array, the Berkeley Gas-Filled Separator (BGS) and a radioactive beam capability (BEARS), which provide new capabilities at the 88-Inch Cyclotron for exploring very exotic nuclei. Other unique facilities that have lead to important discoveries and new physics insights are a magneto-optical atom trap, a fast gas-phase chemistry apparatus and various particle detector systems. In addition, the development of a next generation gamma-ray array (GRETA) and a ^{14}O source for precision beta-decay measurement have made significant progress in this year.

The 88-Inch cyclotron is a national facility and experimental proposals are reviewed by a program advisory committee. The cyclotron provides beams of most elements using two state-of-the-art ECR ion sources. Beams from helium to neon are available with energies up to 30 MeV/nucleon and for heavier beams the maximum energy decreases with increased mass, reaching 5 MeV/nucleon for lead. The high intensity, high reliability as well as ease of changing beam types and energies make the 88-Inch Cyclotron the ideal accelerator for both nuclear structure and reaction studies. In FY98, the cyclotron provided beam for 65 nuclear science experiments for a total of 3825 hours of beam on target.

Heavy Element Nuclear and Radiochemistry Program

The construction of the Berkeley Gas-Filled Separator (BGS) was completed in 1998 and commissioning experiments were carried out successfully in December 1998. The BGS has a large acceptance, which is achieved through large aperture magnets and being gas-filled to maintain a single average charge state, and consequently has a very high sensitivity of 0.5 event/day/pb. In the first experiment, a 51V beam on a ^{208}Pb target with a cross section of 100 pb, a beam rejection factor of 1015 was achieved and the measured acceptance agreed with the design value. A broad research program is beginning. It includes the production and measurement of the physical and chemical properties of new heavy elements ($Z > 112$), studies of proton drip-line nuclei, and, in combination with a gamma-ray detector array such as the 8-pi or Gammasphere at the target position, it will open up new opportunities for the study of the structure of exotic nuclei.

Exotic Nuclei

BEARS, Berkeley Experiments with Accelerated Radioactive Species, is an initiative to develop a light ion proton-rich radioactive beam capability at the 88-Inch cyclotron. It uses radioactive nuclei produced at the medical cyclotron in building 56. This year the acceleration of the first beam of ^{11}C was achieved and

one experiment was carried out with this beam. So far, the development and experiments have been performed in "batch" mode where long lived ^{11}C (20min.), in the form of CO_2 , is transported to the 88-Inch cyclotron in a cold trap and then injected into the AECR source. A very high ionization efficiency of 11% to the 4+ charge state was achieved. A 125 MeV beam with an intensity of 3×10^7 to 1×10^8 particles/sec was delivered to the target. The next step of the project, the construction of a 300m transfer line connecting the two cyclotrons, is proceeding and will be complete in 1999. It contains multiple capillary tubes for transporting radioactive isotopes either through continuous gas flow or attached to aerosols in a helium-jet. Other beams such as ^{13}N , ^{14}O , $^{17,18}\text{F}$ and ^{19}Ne are being planned.

Nuclear Structure

The 8-pi gamma-ray array from Chalk River was installed in cave 4C and operation began April 98. This array, with its multiplicity/total energy inner ball and a CsI detector array for light charged particles, is operated as a user facility. During this year 21 experiments, involving 13 institutions (both US. and overseas), have been carried out. Plans are being made to operate 8-pi Ge detectors at the target and/or focal plane location of the BGS.

The goal of the nuclear structure program is the understanding of nuclear properties as a function of angular momentum, isospin and excitation energy. The experimental program is carried out using both Gammasphere and the 8-pi detector array. For example, the 8-pi was used to search for the predicted new phenomenon of Jacobi shape transitions in nuclei, preliminary results imply a large change in the moment of inertia at high angular momentum in $A=90$ nuclei and further experiments are planned to study this phenomenon. Also at the 8-pi first tests were carried out to investigate new reactions to produce neutron-rich nuclei using target fragmentation reactions. The feasibility of this approach was established and states with spins up to 12 were populated in nuclei such as ^{48}Ti using the $^{12}\text{C} + ^{51}\text{V}$ reaction at 32 MeV/A. At Gammasphere, continued studies of the shears mechanism (a new way of generating angular momentum) resulted in the observation of a new region of shears bands in near spherical nuclei with $A \sim 110$. In addition, a model of the shears mechanism in terms of particle-hole coupling and the interaction with phonons was further developed. Other topics currently being pursued include the structure of heavy nuclei ($Z > 92$), proton-neutron pairing in odd-odd $N=Z$ nuclei, studies of even-even $A \sim 100$ nuclei near $N=Z$ (shell-model states around ^{100}Sn), and the mixing of states at moderate temperatures through an analysis of the number of decay pathways.

The research and development of a next generation of gamma-ray detector arrays, GRETA (Gamma-Ray energy Tracking Array), passed several important milestones this year. This new concept in Ge detector arrays has the potential of having 100 to 1000 times the sensitivity of Gammasphere. The first prototype element of a 12-segmented Ge detector was tested using digital electronics. The shape of the measured net and induced signals agreed with those predicted by early simulations. The results of the detailed data analysis provided the segmentation size needed for achieving the required position resolution, enabling the design of a 36-segmented detector to be finalized and the 12-segment detector was returned to the manufacturer for further segmentation. Decomposition of multiple hits in a segment was achieved with an algorithm in two-dimensions. A three-dimensional program will be developed to compare

with the results from the 36-segment prototype. A "Workshop on physics with GRETA" took place at LBNL on February 5-7, 1998. Based on the discussion a proposal was submitted to DOE for the construction of a 9-element array. A GRETA advisory committee was established following the workshop to provide active community planning and participation of the R/D efforts.

Nuclear Reactions

The study of multifragmentation, the emission of complex fragments from hot nuclei, has been a rich source of new theoretical understanding of this seemingly complex process in terms of simple stochastic relations. The Poissonian shape of the emission probability and the scaling of the probability with temperature have been demonstrated. Furthermore, the parameters of the Poisson distribution provide a measure of the source size. Shell effects on fission barriers are being studied from high precision fission cross section measurements on several Po and Os isotopes.

Weak interaction and Astrophysics

The weak interaction group takes advantage of the unique capability of the 88-Inch cyclotron of providing high intensity light ion beams, to produce exotic nuclei for the precision studies of weak interaction parameters in the search for physics beyond the standard model. A new detector system is near completion which will be used to detect beta particles in coincidence with the recoiling nuclei from the decay of the trapped ^{21}Na atoms. This measurement will provide the beta-neutrino correlation, setting limits on scalar and tensor contributions to the weak interaction. A new target and a transfer line for the production of ^{14}O and injection into an ion source has been constructed and tested. A high ^{14}O intensity of 108 was achieved. An ECR is being assembled, the ions from the source will be implanted in a thin foil for precision beta-spectrum measurements to test the conserved Vector Current hypothesis.

The nuclear astrophysics group has continued to measure nuclear properties important to the understanding of the formation of the elements and isotopes found in the universe. An experiment has set the most stringent limit on the cosmic-ray lifetime of ^{56}Ni . The decay rate of ^7Be in different host material was measured. A variation of up to 0.4% in decay rate was observed.